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Communication

The Association between Anthropometric Variables, Functional Movement Screen Scores and 100 m Freestyle Swimming Performance in Youth Swimmers

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Abstract: This study examined the association between anthropometric variables, Functional Movement Screen (FMS) scores and 100 m freestyle swimming performance in early adolescent swimmers. Fifty competitive, national level, youth swimmers (21 males, 29 females, mean age ± SD = 13.5 ± 1.5 years, age range 11–16 years) performed an "all-out" 100 m freestyle (front crawl) swim as fast as they could in a 50 m pool. A median divide for 100 m timed swim was also used to divide the sample into faster or slower groups. Height, body mass, skinfolds and limb lengths were also assessed. Maturation was calculated by proxy using anthropometric measures and participants also undertook the FMS as a measure of functional performance. Backwards linear regression indicated a significant model ($p = 0.0001$, Adjusted $R^2 = 0.638$) explaining 63.8% of the variance in swim performance with total sum of skinfolds, upper leg length, lower leg length, hand length and total height significantly contributing to the model. Swimmers who were classed as fast had lower total sum of skinfolds ($p = 0.005$) and higher total FMS score ($p = 0.005$) compared to their slower peers. In summary, this study indicates that anthropometric variables significantly explained the variance in 100 m freestyle swimming performance in youth swimmers.

Keywords: pediatric; skinfolds; limb length; functional performance

1. Introduction

Understanding the physical and anthropometric factors that underpin performance in the sport of swimming is important in relation to talent development and targeting training programs effectively [1]. The use of anthropometry and physical testing is prevalent in many talent identification and talent development programmes including those of the Federation Internationale De Natation (FINA) [2]. As such examining the impact of anthropometric variables on swimming performance in pediatric swimmers is of interest to scientists and coaches alike. A body of literature has documented how anthropometric and other variables might predict pediatric swimming performance [3–7]. Anthropometry alone, however, may not be best suited for monitoring pediatric swimmers. For example, Geladas *et al.* [7] reported that 100 m freestyle swimming performance was best predicted by a combination of anthropometric and physical tests ($r = -0.22$ to -0.31) in a sample of 263, 12–14 year old swimmers. Thus, there is a need to better understand how these factors might influence swimming performance in adolescent swimmers.

In recent years there has been an increase in the use of pre-participation movement screens as a means to quantify functional movement as well as predicting injury risk and sports performance [8]. The Functional Movement Screen (FMS) [8]), is one such measure which is predictive of injury risk [9] and has been shown to improve following online video-based compared to fully supervised resistance exercise in adolescent basketball athletes [10]. Recent work by Paszkewicz *et al.* [11] has also reported that the FMS can discriminate between levels of pubescence and detect alterations during the pubertal growth cycle in children and adolescents aged 8–14 years old. The FMS comprises seven movement tests that employ a variety of positions and movements closely related to normal growth and development [12]. It is conceptualised that fundamental movements, such as those tested by the FMS, operate as the basis of more complex movement patterns used in common daily activities [8,9]. As such the use of the FMS offers a practical way by which to evaluate the functional movement patterns that underpin all aspects of human movement. Recent longitudinal research with 121 track and field athletes has also supported the efficacy of this method. Chapman *et al.* [13] reported that athletes who scores a FMS composite score of 14 or higher had a significantly greater performance improvement in their disciplines over the following year compared to athletes who scored less than 14 on the FMS. Conversely, data presented by Parchman and McBride [14] reported no significant association between FMS scores, golf club head speed, and various fitness tests in 25 adult golfers. Other research with a non-athletic child population has also reported that FMS scores were significantly related to body mass index [15], with higher BMI being associated with poorer FMS performance. Despite this data, few studies have examined how these functional movement patterns develop in adolescents generally and no studies to date have examined if and how FMS performance might be associated with anthropometric factors and performance in adolescent athletes.

The aim of this study was to examine the association between anthropometric variables, functional movement screen scores and 100 m freestyle swimming performance in trained adolescent swimmers.

We hypothesized that both anthropometric variables and functional movement screen scores would be significant predictors of 100 m freestyle swimming performance.

2. Method, Results, Discussion

2.1. Method

2.1.1. Participants

Following institutional ethics approval, informed consent and parental informed consent, 50 competitive youth swimmers aged 11–16 years (21 males, mean age ± SD = 13.6 ± 1.7 years and 29 females, ages 11–16 years, mean age ± SD = 13.4 ± 1.3 years) participated in this study. The swimmers were currently competing at national level and were part of an Amateur Swimming Association beacon squad. Individual participants were currently engaged in 4 to 9 formal training sessions per week (mean ± SD of training sessions per week = 6.9 ± 1.2 sessions/week). Participants were recruited via formal approach to coaches at Amateur Swimming Association swimming clubs in the West Midlands, UK with inclusion criteria being currently competitively included in a national level beacon squad.

2.1.2. Anthropometry

Height (cm) and body mass (kg) were assessed using a SECA stadiometre and weighing scales (±0.1 cm and 0.1 kg, respectively; SECA Instruments Ltd., Hamburg, Germany). Skinfolds were taken on the right hand side of the body using Harpenden skinfold callipers (±0.2 mm Harpenden Instruments, Cambridge, UK) from the triceps, biceps, subscapular, iliac crest, supraspinale, mid abdominal, front thigh and medial calf sites. Individual skinfolds were summed to create a total sum of skinfolds measure to reflect overall adiposity [16]. Limb lengths were assessed using a non-stretchable tape measure and consisted of measures of upper arm, lower arm and hand lengths and upper leg, lower leg and foot lengths. Anthropometric measurements were collected by an experienced anthropometrist, following guidelines from the International Society for the Advancement of Kinanthropometry (ISAK) [16]. In addition, physical maturation was assessed using the predictive equation of Mirwald *et al.* [17] based on age, height, leg length and sitting height by predicting the age at peak height velocity (APHV). Mean ± SD of APHV was 14.56 ± 0.83 years).

2.1.3. Functional Movement Assessment

Each participant also underwent functional movement assessment using the FMS™ screening system (see functionalmovement.com). The FMS consists of seven tests; Deep squat, in-line lunge, hurdle step, shoulder mobility, stability push-up, rotational stability and active straight leg raise, which challenge an individual's ability to perform basic movement patterns that reflect combinations of muscle strength, flexibility, range of motion, coordination, balance and proprioception [8,18]. The FMS was administered by a trained rater using standardised procedures, instructions and scoring [8,18]. Each participant was given 3 trials on each of the seven tests (deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk-stability push-up and rotary stability) in accordance with recommended guidelines [8,18]. Each trial was scored from 0 to 3 with higher scores reflecting better functional movement. For each test, the highest score from the three trials was recorded and used to generate an overall composite FMS score with a maximum value of 21 and in accordance with recommended protocols [8,13]. Comprehensive instructions for each movement are also provided elsewhere [18] and readers are referred to these for in-depth detail on the development and functional basis for the FMS. A pilot study was also conducted with 10 participants to determine test re-test (two-week) agreement between the investigators conducting the FMS rating in the present study. Kappa values revealed excellent test re-test agreement for total composite score and individual FMS tests (Kappa = 0.97 to 1). Intraclass correlation coefficient (ICC) for the three attempts at each of the seven tests taken were also high with all ICCs >0.9.

2.1.4. Measures of Swimming Performance

The participant's coaching staff provided information regarding each participant's 100 m freestyle personal best swim time. Participants also undertook a timed 100 m freestyle swim. In the timed 100 m swim, participants were requested to perform an "all-out" 100 m freestyle (front crawl) swim at maximal speed in a 50 m pool. Participants started the timed swim, diving in from the side of the pool and performing normal turning action at the end of each length. Prior to the trial, swimmers performed a 400-m warm-up swim, followed by a 10 min passive resting period before the 100-m all-out trial, consistent with procedures used previously by Latt *et al.* [19]. Moreover, timed freestyle swim performance was significantly related to individual personal best times ($r = -0.967$, $p = 0.0001$) for the swimmers.

2.1.5. Statistical Analysis

Pearson's product moment correlations were employed to examine the association between timed freestyle swim performance, FMS score, APHV and anthropometric variables. Backwards linear regression was then employed to examine the amount of variance in timed swim performance that could be explained from FMS score, APHV and anthropometric variables. A fully saturated model was employed where all variables were included in the analysis in the first instance and variables removed until a parsimonious model was determined. A median split for timed freestyle swim performance was also used to divide the sample into faster or slower groups. A series of 2 Gender (*i.e.*, male *vs.* female) by 2 swim speed (*i.e.*, faster *vs.* slower) ways analysis of covariance (ANCOVA) controlling for APHV were used, employing backwards elimination to achieve a parsimonious solution, to examine any differences in FMS score and anthropometric variables as a result of gender or timed freestyle swim performance. The use of ANCOVA in this way allows for any independent differences (main effects) in swim speed between boys and girls and faster and slower swimmers to be determined whilst also allowing any interactive effects between gender and faster and slower swimmers to be determined. In addition, the inclusion of APHV as a covariate provides a mean to determine the independent association between APHV and FMS or anthropometric variables and also any interaction effects between APHV and gender and APHV and fast *vs.* slow swimmers to be determined (See Field [20] for an overview). The statistical package for social sciences (Version 20, SPSS Inc., Amonk, NY, USA, 2011) was used for all analysis.

2.2. Results

Pearson's product moment correlations indicated significant relationships between timed freestyle swim performance and all the dependent variables except for lower leg length (all $p < 0.05$, $r = -0.264$ to 0.654, see Table 1). Backwards linear regression indicated a significant model (F 5.49 = 18.3, $p = 0.0001$, Adjusted $R^2 = 0.638$) explaining 63.8% of the variance in swim performance with total sum of skinfolds ($\beta = 0.041$, $p = 0.05$), upper leg length ($\beta = 0.428$, $p = 0.005$), lower leg length ($\beta = 0.858$, $p = 0.001$), hand length ($\beta = -1.709$, $p = 0.0001$), and total height ($\beta = -0.67$, $p = 0.0001$), significantly contributing to the model.

Results from ANCOVA analysis, controlling for maturation indicated significant gender main effects for foot length ($F = 20.6$, $p = 0.0001$), lower leg length ($F = 5.6$, $p = 0.018$) and hand length ($F = 6.5$, $p = 0.019$) with boys having higher mean values than girls (See Table 2). Boys however, had significantly ($F = 8.2$, $p = 0.005$, see Table 2) poorer total FMS score compared to girls. Significant main effects for swim speed (fast *vs.* slow) were also evident for total sum of skinfold ($F = 11.1$, $p = 0.005$, See Table 2) and Total FMS score ($F = 9.4$, $p = 0.005$, See Table 2). Swimmers who were classed as fast swim speed had lower total sum of skinfolds and higher total FMS score compared to their slower swim speed peers. There were also significant gender X fast *vs.* slow interactions for height ($p = 0.013$, See Table 3) and body mass ($p = 0.0001$, See Table 3). Boys who were classed as fast swim speed were significantly taller and had significantly greater body mass than girls who were classed as fast swim speed. There were no significant differences in height or body mass between boys and girls who were classed as slow swim speed swimmers. There were no significant main effects or interactions for upper leg length ($p > 0.05$). Maturation (APHV) was not significant in any of the analysis, ($p > 0.05$). There were also no significant differences in APHV between boys and girls or those classed as fast or slow for swim speed (all $p > 0.05$).

2.3. Discussion

The main findings of this study are: (1) that anthropometric variables (total sum of skinfolds, upper leg length, lower leg length, hand length and total height) were able to explain 63.8% of the variance in 100 m maximal freestyle swimming performance; (2) that swimmers classed as faster, based on a median split, had lower total sum of skinfolds and exhibited better functional movement patterns than their slower peers, after controlling for APHV; (3) Boys had larger foot, lower leg and hand length and poorer functional movement performance than girls.

Table 1. Pearson's product moment correlations (r) between 100 m timed swim performance, anthropometric variables and Functional Movement Screen (FMS) score in competitive youth swimmers.

Performance variable	Height (m)	Mass (kg)	Upper arm length (cm)	Lower arm length (cm)	Hand length (cm)	Upper leg length (cm)	Lower leg length (cm)	Foot length (cm)	Sum of skinfolds (mm)	Total FMS (0–21)
100 m freestyle timed swim	−0.654 **	−0.543 **	−0.561 **	−0.483 **	−0.626 **	−0.350 *	−0.264	−0.494 **	0.410 **	−0.333 *

* and ** $p < 0.05$ and 0.01 respectively.

Table 2. Mean (±SE) of anthropometric variables and total FMS score between boys and girls and swimmers classified as faster or slower ([a] $p = 0.019$ compared to girls, [b] $p = 0.018$ compared to girls, [c] $p = 0.0001$ compared to girls, [d] $p = 0.005$ compared to girls, [e] $p = 0.005$ compared to slow).

Sample	Timed freestyle swim performance (s)	Height (cm)	Body mass (kg)	Upper arm length (cm)	Lower arm length (cm)	Hand length (cm)	Upper leg length (cm)	Lower leg length (cm)	Foot length (cm)	Sum of skinfolds (mm)	Total FMS (0–21)
Pooled data (n = 50)	68.8 (1.0)	164 (1.5)	54.4 (1.4)	32.2 (0.43)	25.5 (0.59)	18.4 (0.19)	52.2 (0.62)	49.2 (0.62)	24.9 (0.32)	94.2 (4.8)	15.9 (1.4)
Boys (n = 21)	68.7 (1.1)	169 (2.9)	58.9 (2.7)	32.9 (0.47)	25.3 (0.68)	18.8 (0.24) [a]	52.9 (0.81)	50.6 (0.86) [b]	26.1 (0.31) [c]	84.6 (6.3)	15.2 (0.26) [d]
Girls (n = 29)	69.9 (0.93)	161 (0.9)	51.2 (1.2)	31.6 (0.39)	25.6 (0.61)	18.1 (0.20)	51.7 (0.70)	47.8 (0.71)	23.8 (0.38)	98.3 (5.1)	16.3 (0.22)
Fast (n = 24)	63.9 (0.9)	169 (2.1)	58.5 (2.2)	32.8 (0.41)	26.3 (0.53)	18.9 (0.27)	52.3 (0.77)	49.2 (0.78)	25.3 (0.33)	77.7 (6.4) [e]	16.4 (0.24) [e]
Slow (n = 26)	74.7 (1.1)	161 (1.2)	54.4 (1.0)	31.4 (0.48)	24.1 (0.61)	18.0 (0.25)	52.3 (0.82)	49.7 (0.84)	24.7 (0.36)	106.4 (6.9)	15.2 (0.27)

Table 3. Mean (±SE) of anthropometric variables and total FMS score between fast and slow boys and fast and slow girls ([a] $p = 0.0001$ compared to slow boys, [b] $p = 0.021$ compared to fast girls, [c] $p = 0.0001$ compared to slow girls, [d] $p = 0.001$ compared to slow boys, [e] $p = 0.003$ compared to fast girls, [f] $p = 0.001$ compared to slow girls).

Sample	Timed freestyle swim performance (s)	Height (cm)	Body mass (kg)	Upper arm length (cm)	Lower arm length (cm)	Hand length (cm)	Upper leg length (cm)	Lower leg length (cm)	Foot length (cm)	Sum of skinfolds (mm)	Total FMS (0–21)
Fast boys (n = 14)	61.4 (1.3)	176 (2.7) [a,b,c]	64.2 (2.7) [d,e,f]	35.3 (0.78)	27 (0.49)	19.8 (0.34)	55.2 (0.99)	52.7 (1.01)	27.1 (0.51)	73.0 (4.7)	16.1 (0.51)
Slow boys (n = 7)	75.9 (1.9)	157.5 (3.9)	49.9 (3.8)	30.4 (1.4)	22.8 (1.0)	18.1 (0.55)	50.7 (1.8)	48.9 (2.0)	25.5 (0.89)	114.9 (20.1)	14.5 (0.429)
Fast girls (n = 12)	66.4 (1.4)	162 (0.88)	52.0 (1.6)	31.6 (0.35)	25.7 (0.81)	18.4 (0.31)	51.2 (1.2)	47.1 (1.1)	24.2 (0.5)	87.6 (7.4)	16.5 (0.26)
Slow girls (n = 17)	73.5 (1.2)	158.3 (1.2)	50.6 (1.8)	30.7 (0.43)	25.2 (0.67)	17.6 (0.17)	51.1 (0.74)	48.0 (0.84)	23.2 (0.29)	107.9 (7.4)	16.1 (0.23)

Although anthropometric predictors of swim performance have been examined in prior literature [4–8] no studies to date have examined how functional movement relates to swim performance in either adults or youth swimmers. As swimmers start heavy training at a relatively young age it is important to assess which parameters may be the best predictors of sprint swimming performance to enhance youth development programmes [19,21]. For coaches such data is useful in highlighting the key anthropometric variables that might best relate to 100 m freestyle performance in early adolescent swimmers after controlling for any impact of physical maturation. It is however important to note that the results presented here are only indicative of anthropometric profiles at one given point in time. If such anthropometric profiling were to be used for talent identification a longitudinal design alongside monitoring of training loads within a periodised programme would need to be undertaken to better understand predictors of swimming performance. Furthermore, as faster swimmers had better FMS scores, this study highlights potential utility of the FMS in swimming. However, there was a greater spread of FMS scores seen in boys (fast boys = 16.1; slow boys = 14.5) compared to girls (fast girls = 16.5; slow girls = 16.1). This variance might explain why anthropometric variables significantly contributed to the regression model whereas FMS score did not. This point is however speculative and the reason for the variance of FMS scores in boys in not known. Subsequent a posteriori analysis of data that APHV values were higher for fast boys (14.5 ± 0.2 years) compared to slow boys (14.1 ± 0.3 years). Although there was no significant difference in APHV, this may have contributed to the higher FMS scores in fast boys compared to their slower counterparts. However, the cross sectional nature of the data presented here do not allow any insight as to whether those athletes with better functional movement pattern swim faster or whether those athletes with greater swim performance develop better functional capability. Further research, including longitudinal investigation of functional movement development, in youth swimmers is therefore needed.

Our results are supportive of prior research that has also identified anthropometric variables as important predictors in swimming [6,7,19,22]. In particular, prior studies have suggested that taller swimmers glide better through the water [5,23] and also have a larger arm span, benefitting swimming efficiency (via a larger stroke length) [24].

We acknowledge however that only anthropometric variables relating to leg and arm length and total body fatness were examined in the present study. Future research with youth swimmers would therefore be useful which also assesses other anthropometric variables such as arm span and arm and leg volume to provide a more comprehensive anthropometric profile of competitive youth swimmers.

By categorizing swimmers regarding their swim speed, this study also evidenced that "faster" young swimmers displayed better functional movement patterns compared to their "slower" counterparts. This is an important and novel finding with practical applications. Prior research with adults has suggested lower FMS scores are related to increased injury risk in adults [25]. While investigating the association between FMS score and injury risk/history was beyond the scope of the present study, this appears an interesting avenue for future research. The research findings presented in the present study are supportive of research that has identified that higher FMS scores are related to enhanced performance in adult track and field athletes [13]. However, it is difficult to compare the present study with the prior work as few studies have presented FMS data in young people and none to date appear to have presented FMS scores in youth athletes. It is also important to note that only the total FMS score was utilised in the present study. The total FMS score provides an indication of overall functional movement performance [8,13].

Examining how scores on the individual tests within the FMS relates to athletic performance would be useful in developing the understanding of the FMS-performance relationship in youth athletes. However, in order to accomplish this, a far larger sample size than that in the present study would be required. Access to such a sample size of national level youth swimming performers is logistically difficult to obtain. Consequently, this is a direction for future research. It is also not possible within the present study to assert whether improving FMS leads to enhanced swimming performance or whether those who are better swimmers exhibit better functional movement patterns.

3. Conclusions

The present study indicates that anthropometric variables (63.8%) significantly explained the variance in 100 m freestyle swimming performance in early adolescent swimmers. Moreover, after adjusting for physical maturation, swimmers classed as faster had lower sum of skinfolds and better functional movement patterns than swimmers classed as slower. While gender differences were logically observed for anthropometrical variables, boys displayed lower functional movement ability than girls.

Author Contributions

Daisy Bond, Laura Goodson, Michael J. Duncan and Samuel W. Oxford designed the study, Daisy Bond and Laura Goodson collected the data. Michael J. Duncan, Alan M. Nevill and Samuel W. Oxford analysed and interpreted the data. Michael J. Duncan, Samuel W. Oxford and Alan M. Nevill wrote the manuscript. All authors critically reviewed, contributed to and approved the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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